Turbine Development and Integration Issues

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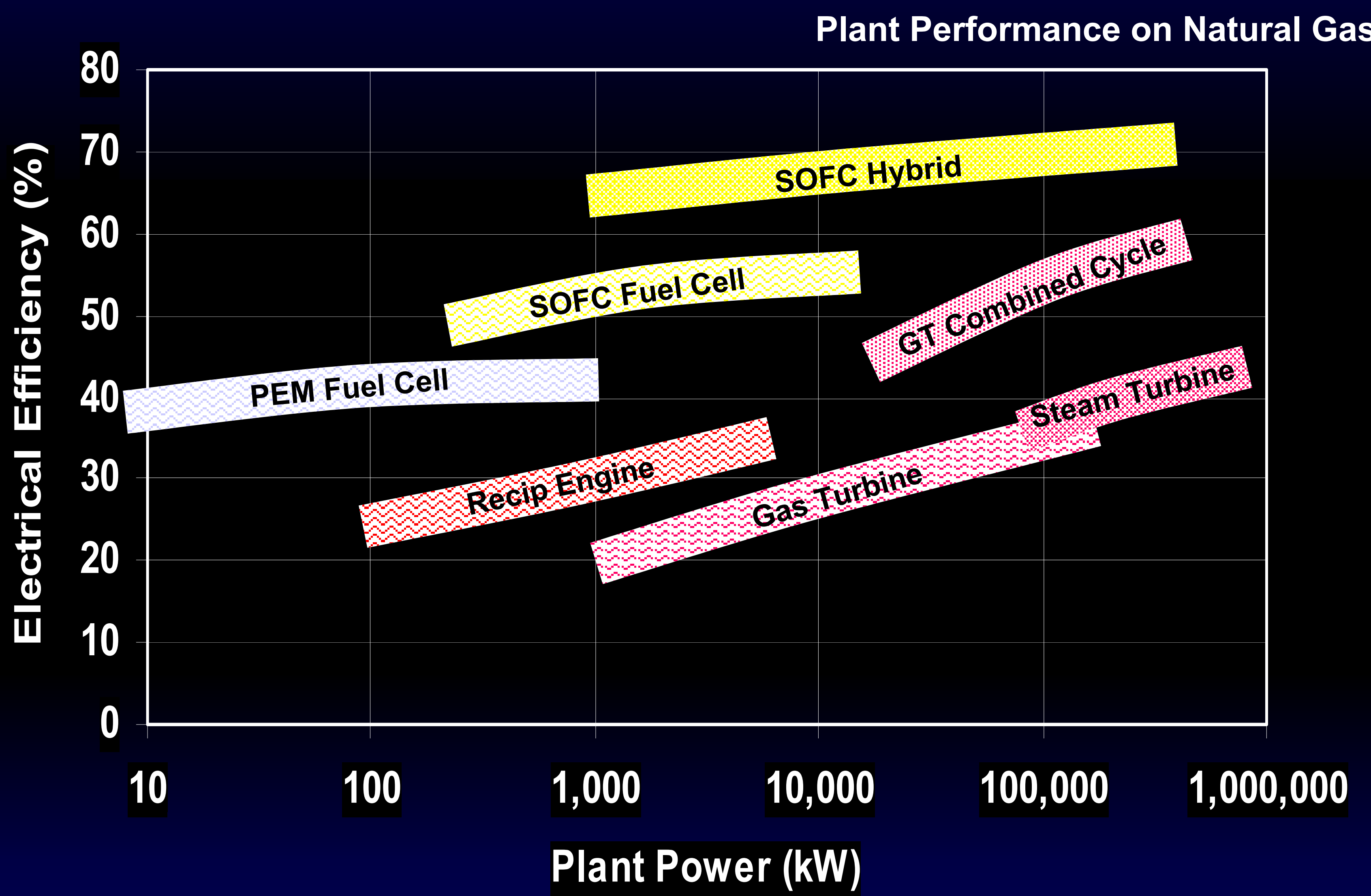
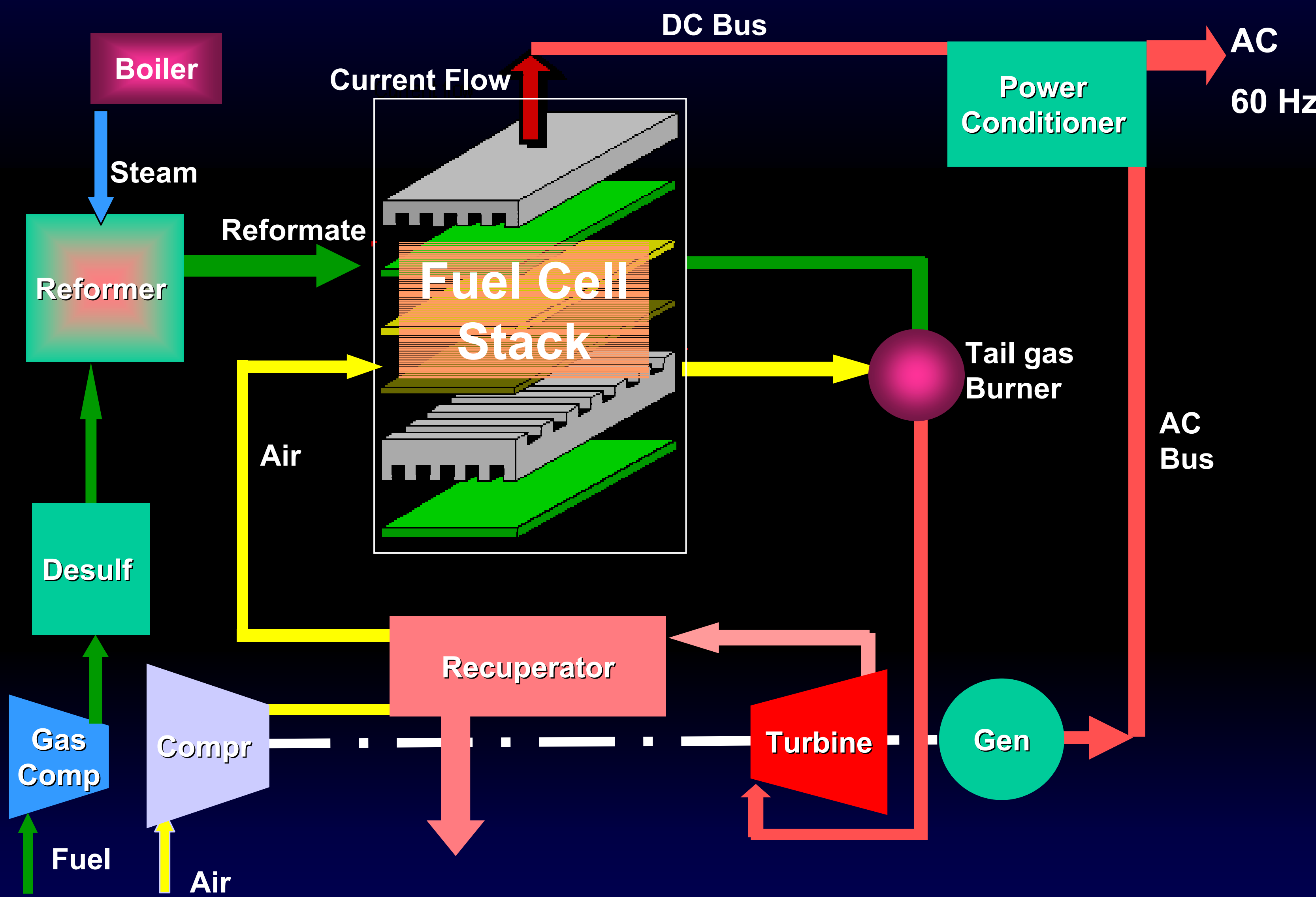
Power Generation Technologies



SOFC Hybrid Power Plant



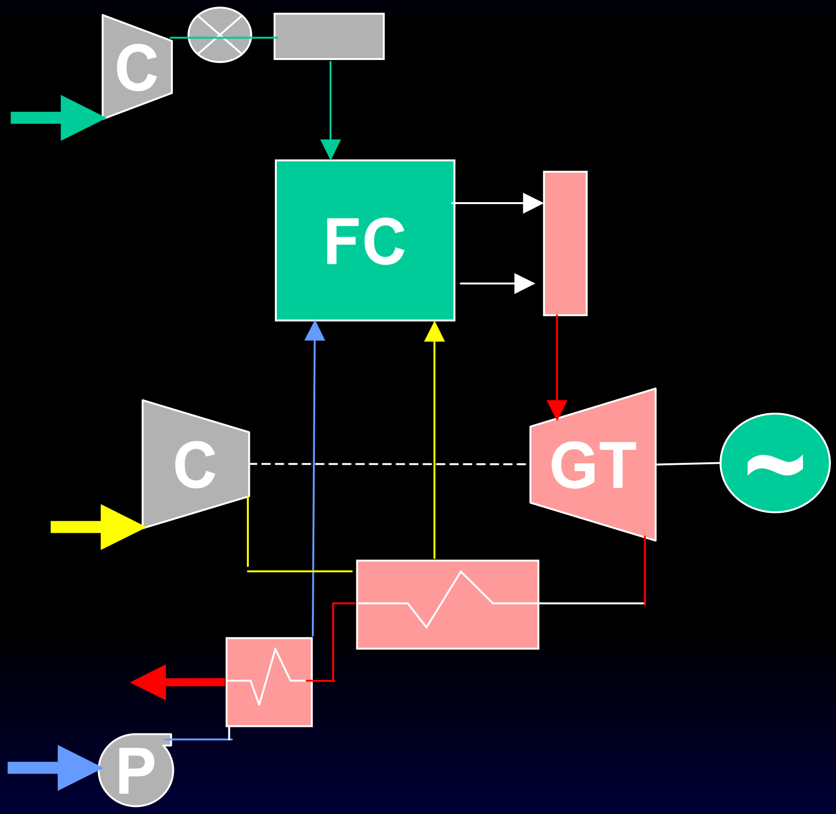
Drivers for SOFC Hybrid Systems

- **High efficiency**
  - Turbine hybrid cycles +65%
  - High efficiency potential at small sizes
- **High environmental attractiveness**
  - Ultra low emissions possible, low noise
  - Distributed power potential
- **Cogeneration potential**
  - Ultimate energy utilization
- **Fuels flexibility**
  - Natural gas, biomass, coal gas, oil and gasoline
- **Size and siting flexibility**
  - Full range of power generation sizes

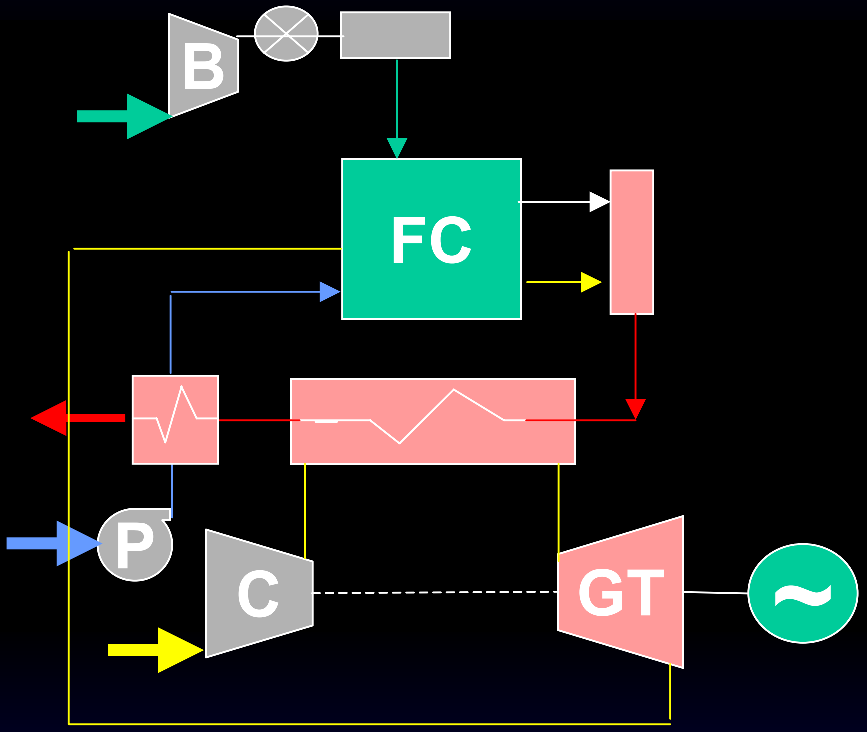
Potential Future Power Generation Technology

Overview of Generic Cycle Layouts

- Direct cycles



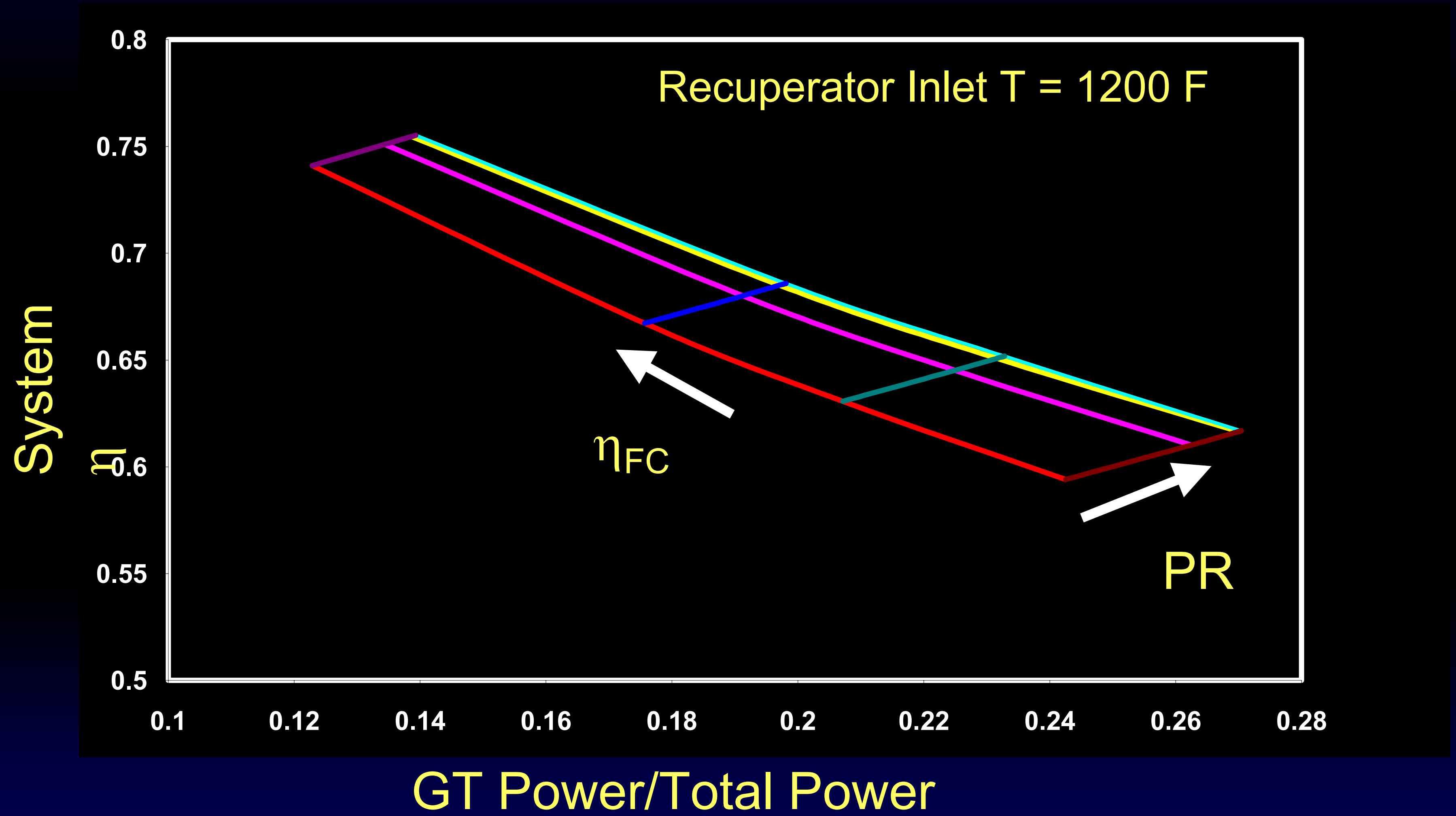
- Indirect cycles



Key Issues: GT Pressure Ratio & inlet T

Key Issues: GT Pressure Ratio & High Temp Heat Exchanger

Implications of Power Split on System Performance



Primary requirements of The Gas Turbine

- Higher GT efficiency improves overall system.
- For direct cycles both GT pressure ratio and inlet temperature are limited by the specific FC Stack.
- For indirect cycles the GT inlet temperature is limited only by the heat exchanger material selection and cost.
- In all cases the power split, fuel utilization in the fuel cell, and stack design controls the gas turbine and system optimum

Implies Gas Turbine Design for a Specific Fuel Cell is Required

System Challenges

To achieve an optimized Hybrid Power Plant the Fuel Cell and Gas Turbine need to be designed together

System Challenges

- Turbine System
- Flow Handling System
- Auxiliary Systems

Turbine System

- Micro/Mini-turbine Based System
  - Low Pressure Ratio & Operating Temperatures
  - Currently no commercial systems available
- Fuel Cells & Gas Turbines are Dynamically Different Systems
  - Starting
    - Fuel cells have long time constants while gas turbines do not
  - Stopping - Loss of load event
    - Both systems react differently, each with it’s own control challenges
  - Load Sharing and Grid Participation
    - Optimization challenge to achieve best performance

Flow Handling System

- Physical System Challenges
  - Plumbing and Valving of Hot, Pressurized Gas
    - TCE challenges for large systems
  - Control Sensors in Flow
- Combustion/Oxidation of Gases
  - Low Btu Combustion
    - Stability of H_2 combustion in Premixed Systems
    - Catalytic combustor challenges
  - Starting the Combustor (Ignitability)
  - Stored energy considerations

Auxiliary Systems

- A Significant Portion of any Power Plant
  - Fuel Compression
    - Availability of product (depending on size of plant)
  - High Temperature Heat Exchangers
    - Availability, Reliability, Maintainability
  - High Temperature Blowers, Valves, Piping
    - All contribute to the complexity and cost of the system
  - H2 Sensors
    - Turbines typically controlled by exhaust temperature
  - Safety systems (physical, electrical, chemical)

Auxiliary Systems are key to System Performance

Technology Status and Plans

- **Heat Exchangers**
  - Status: Limited by cost of materials to 1200º F (650C)
  - Significant improvements required in both reliability and cost
  - Develop multi function, unified heat exchanger concepts
    - Too may components currently
    - Integrate fuel pre-heater, water pre-heater, reucperator etc.
- **Gas Turbine**
  - Status: No off the shelf system available for each specific FC power plant configurations.
  - Need to develop specific designs for the FC based power plant (technology exists)
- **Controls**
  - Status: Details of transients between the slow response, high thermal inertia fuel cell and heat exchanger vs. the fast response gas turbine is not understood
  - Improve understanding of the control system dynamics and interactions including power conversion systems

Technology Status and Plans

- **Balance of Plant (BOP)**
  - Work to minimize BOP by clever integration of the plant components
  - Most sub-systems readily available
    - High temperature blowers an exception
  - Develop application specific components as required
- **Power Conversion**
  - Status: Off the shelf systems available for specific power ranges.
    - Efficiency of a fuel cell hybrid plant is significantly impacted by power conditioner performance.
  - Need modular power conditioning system designs
    - Adaptable to range of hybrid plant concepts
    - Drive power conditioning requirements back through system design to set constraints on cell, stack, turbine and controls.

Conclusions

- SOFC-GT Hybrid Systems Offer Significant Promise
  – Unprecedented electrical efficiencies over a wide range of power output
  – Environmentally friendly
  – Fuel flexible
- Considerable Development Efforts Required for Success
  – Must be treated as integrated system design
  – Turbine, heat exchangers, power conversion, and balance of plant all set system constraints.
  – Markets, mission, operability requirements, and fuels have significant impact on design
  – Commercial product success will be determined by life cycle cost of electricity

SOFC-GT Hybrid – *A Disruptive Technology*